COMETS – HOW LABORATORY EXPERIMENTS CAN HELP TO UNDERSTAND THEIR FORMATION AND ACTIVITY.

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Introduction: In the past years, very successful space missions have significantly improved our knowledge of the origin and activity of comets. These space missions have been supported by a variety of different theoretical models and intensive observational campaigns. However, the support from ground-based laboratory experiments has been limited, although they can provide deeper insights into the physics of comets.

Formation and activity: Comets are believed to have formed in the young Solar System by the gentle gravitational collapse of dust clouds, typically consisting of mm- to cm-sized aggregates[1,2]. Due to the nature of this formation scenario, the nucleus is composed mainly of non-volatile dust (the dust-to-ice mass ratio is ~4-9)[3,4], with only minor contributions (in mass) by volatiles.

The nucleus apparently consists of intact dust aggregates which have survived the comet formation process, owing to the small impact velocities during the collapse[5]. For most of their lifetime since formation, comets have orbited the Sun at large heliocentric distances so that they remained almost unaffected by solar radiation. However, gravitational disturbances by the giant planets can change their orbital parameters over time and, thus, comets can get closer to the Sun. In this case, solar illumination leads to the evaporation of water ice and other volatile species and, thus, a volatile-free dust layer forms, covering the water ice. This desiccated dust layer possesses a low thermal conductivity[6], a low gas permeability[7] and a low tensile strength[8]. As a result, the evaporation of the volatile constituents can lead to the ejection of dust aggregates from the surface[9]. These aggregates are composed of micrometric particles[10,11].

Role of laboratory experiments: The laboratory experiments performed so far were very useful to understand the nature of ice-dust samples under cometary-like conditions. However, since we have now data from several fly-by missions and more than two years of escorting a comet from the onset of activity throughout the perihelion (activity maximum) and beyond, the picture of gas and dust production has changed. The major changes are 1) that comets can show activity anywhere on their surface, 2) that comets possess a very high dust-to-ice ratio and 3) that cometary surfaces most probably consist of millimeter- to centimeter-sized aggregates (see Fig. 1 for an image of a cometary analogue material).

These new insights have changed the requirements needed to carry out state-of-the art comet simulation experiments with realistic sample materials. Thus, a new generation of ground-based laboratory experiments is required to interpret the data gathered by previous space missions (especially by the Rosetta mission) and to support future space missions to comets, or to other icy bodies in the Solar System.

The objective of these laboratory experiments is to investigate the fundamentals of cometary activity by performing experiments with appropriate comet analogue materials, such as aggregates composed of silicate particles, granular H_2O ice and CO_2 ice (see Figs. 1 and 2).

In order to study the activity of comets in laboratories on Earth, one has to create optimised analogue materials and ensure realistic environment conditions in which the samples are studied. In particular, a setup must be designed in which gravity is rendered unimportant. This can be achieved by choosing appropriate aggregate sizes (smaller than ~200 µm in radius; see Fig. 3) and correspondingly higher gas-production rates (by adapting the temperature of the samples). The ratio between tensile strength of the dust and subsurface gas pressure can therefore be adjusted to cometary conditions.

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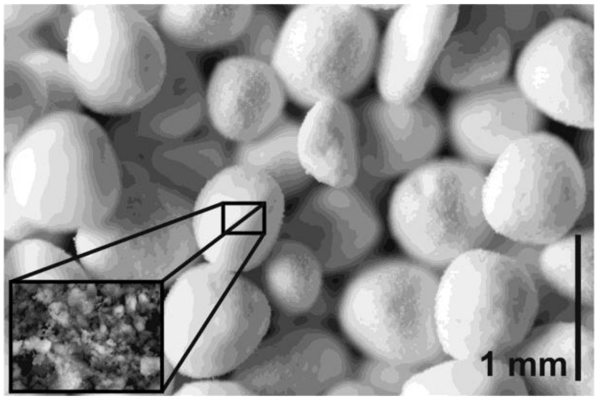

Fig. 1: Image of our mm-sized dust aggregates used in the experiments. The inset shows a SEM image[12] of the irregular-shaped polydisperse silica particles forming the aggregates.

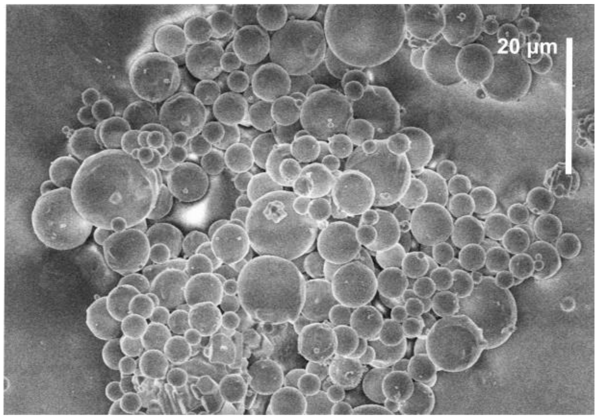

Fig. 2: Granular water ice sample composed of micrometer-sized water-ice particles imaged with a cryo-SEM. These particles are used to generate ice aggregates, or to investigate sintering of ice on the micrometer scale.

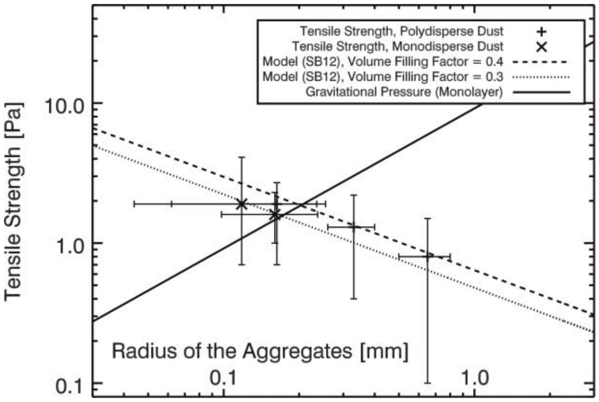

Fig. 3: Experimental results of our tensile strength measurements with dust aggregates[2,13]. For comparison, the model prediction is shown by the dotted and the dashed line for two different volume filling factors[8]. The solid line visualizes the gravitational pressure exerted by a monolayer of dust aggregates.